Advanced piezoelectric ultrasonic transducers for structural health monitoring and photoacoustic imaging

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Safe and reliable operations are of paramount importance in many industries, from aerospace, manufacturing, to oil and gas. To ensure lives, assets and infrastructures are safeguarded, structural integrity often cannot be compromised. Risk management with state awareness is becoming critical, which demands structural health monitoring (SHM) to obtain the real-time data. Market report forecasts the compound annual growth rate for an overall global SHM market is as high as ~18% in the next several years. While the rapid progresses have been seen in computation capability and artificial intelligence, innovations in sensors and the ways of their implementations in the structures are also required for radically upgrading SHM technologies with improved effectiveness at lowered cost.

With deep penetration and capability of detecting various parameters highly indicative of structural integrity, ultrasonic waves, including light-acoustic interactions, have obtained wide industry applications as established nondestructive testing (NDT) means. However, it is still challenging for realizing piezoelectric ultrasonic transducer network widely distributed in the structure to be monitored in practical applications. Besides high cost, high profile and large mass of ultrasonic transducers, uncertain reliability and consistency are also concerned as many factors could affect the mechanical coupling and acoustic wave transmission between the transducers and the structures.

Here we deposited piezoelectric coatings and formed thick-film ultrasonic transducers and transducer array comprising the piezoelectric coatings on the structures to be monitored. The thick-film ultrasonic transducers were produced by direct-write process with highly reduced profile and mass. Two types of piezoelectric coatings were obtained on both flat and tube surfaces, including piezoelectric polymer coatings deposited by aerosol spray process, and lead-free piezoelectric ceramic coatings by thermal spray process. Both fabrication methods are compatible with large area manufacturing and repair processing, promising for achieving scalability and consistency in batch production at low cost.

Our experimental testing results guided by modeling and simulation showed that guided ultrasonic waves as selected were excited and detected with the direct-write thick-film ultrasonic transducers. The feasibility for in-situ detection of various structural defects, including simulated cracks, corrosions, and metallic plastic deformations, was demonstrated using the direct-write transducers and transducer array. Multiple functions of the large area piezoelectric coatings will also be analyzed, and their potential impacts on upgrading SHM technology will be discussed. Finally, advanced ultrasonic transducers recently developed in our lab for photoacoustic detection and imaging are introduced.